CORPS OF ENGINEERS, U. S. ARMY

SOIL COMPACTION INVESTIGATION

REPORT NO. 3

COMPACTION STUDIES ON SAND SUBGRADE

TECHNICAL MEMORANDUM NO. 3-271

WATERWAYS EXPERIMENT STATION

VICKSBURG, MISSISSIPPI

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Report No.	Title	Date
1	Compaction Studies On Clayey Sand	April 1949
2	Compaction Studies On Silty Clay	July 1949
3	Compaction Studies On Sand Subgrade	Oct. 1949

PREFACE

This report presents the results of a combined field and laboratory study performed by the Mobile District, Corps of Engineers, in cooperation with the Waterways Experiment Station, Vicksburg, Mississippi, on the compaction characteristics of a sand subgrade at Eglin Field, Florida. This study is part of a comprehensive soil compaction investigation authorized by the Office, Chief of Engineers, in May 1945 and conducted by the Mobile District in accordance with "Instructions and Outline for Soil Compaction Investigation" dated June 1945. This report was prepared by the Mobile District and condensed and published by the Waterways Experiment Station.

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EGLIN FIELD, FLORIDA

PART I: INTRODUCTION

General Information

1. Eglin Field is located about 50 miles east of Pensacola, Florida, on the Gulf of Mexico, and the military reservation consists of a main airfield and nine auxiliary airfields, all of which have paved landing facilities. Subgrade conditions at each of these landing fields are very nearly identical -- the material being a free-draining medium to fine sand with little or no silt or clay and belonging to the SP soil classification. Low ground-water conditions prevail at the main airfield and at eight of the nine auxiliaries. In 1943 an accelerated traffic test was performed at Auxiliary Field No. 2, using wheel loads up to 50,000 lb. Settlement caused by compaction of the sand subgrade beneath the test track amounted to several inches. Thus the probability of such settlements at Eglin Field was definitely indicated for the heavier plane loads, although there was little evidence that the plane traffic to date has caused more than very minor unevenness in the pavement surfaces.

Purpose of Investigation

2. The tentative design criteria for military airfield pavements for gross plane weights of 300,000 lb, as established on 15 May 1945

by the Office, Chief of Engineers, enumerate the following requirements for sand subgrades: "Clean sand subgrade in unfilled areas and in areas of less than 2-ft fill should be compacted to at least 100 per cent modified AASHO density to a depth of at least 2 ft below the surface of the subgrade. The method used in compacting sand subgrades should be effective to produce compaction to at least 95 per cent modified AASHO density at a depth of 6 ft below the pavement surface". The purpose of the sand compaction investigation at Eglin Field, Florida, as given in "Instructions and Outline for Soil Compaction Investigation", dated June 1945, was to determine the effectiveness of heavy equipment such as tractors, Tournapulls, and the like, in obtaining compaction of free-draining sand subgrades which would meet the above requirements. The investigation at Eglin Field had the further purpose of determining practical compaction methods which could be used during construction of a new runway at that field, designed for ultimate reinforcement to a 300,000-lb plane load.

Scope

3. Briefly, the study consisted of the following phases:

   a. Layout of test sections and compaction with the following types of equipment: 34,000-lb RD-8 tractor; 80,000-lb RD-8 tractor; and 7,000-, 15,000-, 35,000- 60,000-lb rubber-tired wheel loads. Test sections were compacted at three moisture conditions -- natural moisture, sprinkled, and ponded.

   b. Field sampling and testing of test areas.

   c. Laboratory classification testing of samples procured from the test areas.

Definition of Pertinent Terms

4. For purposes of clarity, various terms used in this report are

defined as follows:

Unit -- A unit or test unit consists of an area of natural subgrade which is compacted during the test at a given water condition and under a given compaction effort with a given piece of compacting equipment.

Section -- A section (usually several units) is an area of natural subgrade which is compacted by a given number of coverages with a given piece of compacting equipment.

Modified AASHO compaction -- A modification by the Corps of Engineers of the standard AASHO compaction method, consisting of dynamic compaction in a 4-in.-diameter mold using 25 blows of a 10-lb hammer dropped 18 in. on each of five equal layers.

Pass or coverage -- The terms pass and coverage are used interchangeably in this report and refer to one complete coverage of the area to be compacted by a tractor tread or rubber tire.

Per cent compaction -- Per cent of modified AASHO maximum density.

PART II: PRELIMINARY INVESTIGATION AT MAIN FIELD

Location of Test Sites

5. Prior to receipt of the directive for the sand compaction tests, the Mobile District started a preliminary investigation to assist in the preparation of plans and specifications for the previously mentioned new, very-heavy-bomber (VHB) runway construction at Eglin Field. This test area was located just outside the boundary of the proposed new runway toward the south end of the main field where an existing 4-in. water line made it practicable to test wet and dry areas.

Layout

6. The layout for the preliminary investigation is shown in figure 1. It consisted of a test plot 120 ft wide and 210 ft long which was divided into four test sections as shown, and a special test area comprising seven small square sections 20 ft on a side. The larger test plot was compacted with tractor and with rubber-tired wheel with and without the addition of water. Three of the special test squares were compacted with the tractor in order to determine whether more complete saturation than was obtained in the watered sections of the larger test plot had any beneficial effect on the compaction.

7. The area selected for the test plot was in an old borrow pit. The special test squares were located outside of this borrow pit on natural ground. These conditions materially affected interpretations of the results as borrowing operations materially increased the density.

Equipment

8. An RD-8 tractor weighing approximately 34,000 lb was used on the tractor test sections and an 8-cu-yd Tournapull with only a light load, the gross weight being approximately 28,000 lb, or 7,000 lb per wheel, was used on the rubber-tired areas. The Tournapull had two 16- by 21-in. tires on the rear and two 21- by 24-in. tires on the front. Air pressure in the tires was estimated to be about 45 lb per sq in. Efforts to operate the Tournapull with more load caused it to bog down on the turnarounds at the ends of the track.

Field Sampling and Testing

Test pits

9. The data secured in the preliminary investigation were obtained from 27 test pits excavated at various stages of the tests for the purpose of taking samples and making density and moisture determinations at 1-ft intervals down to a depth of 6 ft. All densities were taken by the sand displacement method. Details of this method are shown by photograph 1, which also illustrates the stable appearance of the vertical sides of the test pit several days after excavation.

Method of determining per cent compaction

10. Samples of the subgrade sand were taken to represent each density test run, and were brought to the laboratory for screen analyses and modified AASHO compaction tests. The results of screen analyses on 160 samples are plotted on figure 2. The uniformity of the material is indicated by the narrow band showing the maximum variation in these samples.

The modified AASHO compaction tests run on a number of these samples showed that the maximum density varied between about 103 and 111 lb per cu ft dry weight. The work required to perform a compaction test on every sample made it necessary to find a more practicable method of determining the maximum density. It was observed that the maximum density determined from the compaction test showed a decrease with an increasing depth of sample, and a review of the mechanical analysis data showed that the per cent passing the No. 200 sieve also decreased with depth of sample. A plot was made of the per cent passing the No. 200 sieve versus the maximum density for all samples on which the compaction test was run. Although the points were scattered, a straight line could be drawn to represent the relationship between these two test characteristics. This plot is shown in figure 3 for both the preliminary investigation and the investigation made at Auxiliary Field No. 2. The relation shown in the left hand plot on figure 3 was used in computing the per cent compaction for all density determinations made during the preliminary investigation.

Application of water

11. The watered test sections of the larger test plot were sprinkled with a 2-1/2-in. fire hose which supplied water at the rate of 91 gal per min. The water was played back and forth across the area being wetted, leaving the surface damp. Prior to tracking for compaction, 36 gal of water per sq yd was used on the two watered test sections. During tractor compaction an additional 32 gal per sq yd was applied to the section being compacted. During Tournapull compaction an additional 41 gal of water was similarly applied to the section being compacted.

Results of Preliminary Investigation

12. Table 1 presents the moisture density data secured in the preliminary test area before and after compaction with the 34,000-lb RD-8 tractor and the 7,000-lb rubber-tired wheel load.

13. Table 2 presents the moisture-density data of the special saturated test area before and after test. The amount of water required to keep free water on the surface of the special test area varied from 1.4 to 2 gal per sq yd per min. Free water was maintained on the surface during tractor compaction and it was observed that the rate of infiltration showed a marked decrease after a few coverages. In order to determine to what extent the saturated condition varied with depth, an auger hole was drilled one hour after tracking in this area (at the approximate time that the free water disappeared from the surface), and the moisture contents were determined to a depth of 4 ft. The first 2 ft of sand had a moisture content of 9 per cent, the third foot had a moisture content of 8 per cent and the fourth had a moisture content of 9 per cent. For the densities shown in table 2 it would require from 18 to 25 per cent moisture to attain complete saturation in this material. This indicates that a relatively low degree of saturation was being obtained, namely 44 to 32 per cent.

14. The minimum requirements for VHB pavement, as given in paragraph 2, are shown in bar-graph 1 at the top of figure 4. It can be noted that a bar is shown for the per cent of compaction at the 4- to 5-ft depth. Since at least 12 in. of pavement will be required, this depth will be about 6 ft below the pavement surface, at which depth 95 per cent

minimum compaction is required. The average of the 2- to 5-ft depth was determined to be 96.7 per cent compaction, using a straight-line variation in density between these depths.

15. The difference between bar-graphs 2, 3 and 12 of figure 4 is of special interest. As stated before, the test plot was in a borrow area, and therefore represents to a certain degree a graded area in cut. The per cent compaction of the test plot is shown by bar-graph 3 of figure 4. The special test areas are outside the old borrow area and are more representative of the natural in-place material as regards density than is the test plot which is located in the borrow area. The per cent compaction of the natural in-place material is shown by bar-graph 2 of figure 4, that of the test plot by bar-graph 3, and that of the special test areas by bar-graph 12. The variations in density of the natural subgrade at the site of the new runway at Eglin Field prior to grading operations was greatest in the top foot. This variation between density determinations at various locations amounts to 12 per cent of maximum AASHO density. The variation decreases with depth and below about 2 ft the density is generally within 2 or 3 per cent of 90 per cent of maximum density. The average in-place density is shown below:

Depth	Density, lb per cu ft	Per Cent Compaction
0 - 1	103.9	94
1 - 2	104.6	95
2 - 3	99.5	91
3 - 4	97.3	90
4 - 5	96.6	90
5 - 6	97.6	91

Thus, compaction efforts must raise the top 2 ft about 6 per cent, and the 4- to 5-ft depth increment about 5 per cent in order to meet the

minimum requirements for VHB paving.

16. Based on the assumption that the test plot represents the approximate effect of previous grading operations, table 1 and bar-graph 3 disclose that such operations appear to raise the per cent compaction in the top 2 ft to the minimum requirements, but lack about 3 per cent at the 5-ft depth of meeting these requirements. This feature indicates the probability of grading operations improving the density to that depth. It is not known what equipment was used in this borrow area, but the ordinary grading equipment being used at Eglin Field comprises 8- and 12-cu-yd Tournapulls, scrapers, tractors weighing up to 34,000 lb, and other similar equipment.

17. According to table 1 and bar-graphs 3, 4 and 5 of figure 4, very little increase in density resulted in the use of 6 coverages of the RD-8 tractor for compaction of the test plot. No appreciable difference could be observed between the sprinkled and the natural-moisture test units. Some slight increase in per cent compaction is noticed in the top 2 ft over that measured prior to compaction. The effect of additional coverages was investigated by making 26 extra coverages bringing the total for these sections to 32. It can be seen from bar-graphs 4, 5, 6 and 7 of figure 4 and from table 1 that the additional coverages of the tractor did not produce any appreciable increase in density over that obtained with 6 coverages.

18. Six coverages of a 7,000-lb wheel load did not appreciably improve the degree of compaction in the test sections as disclosed by table 1 and bar-graphs 8 and 9. The densities of the sprinkled units were slightly higher than those measured in the natural-moisture units

in this particular test. Twenty-six additional coverages were made, making a total of 32, but it can be seen from bar-graphs 8, 9, 10 and 11 of figure 4, and from table 1, that the density of the top 2 ft was increased only from 1 to 2-1/2 per cent and that the other depths were unaffected.

19. Efforts to compact the sand in a saturated state, by first ponding and maintaining free water on the surface during compaction with the tractor in the special square test areas, did not meet with any appreciable measure of success. Comparison of bar-graph 12 with bar-graphs 13, 14 and 15 shows that the density increased some 3 or 4 per cent at the surface over that in the in-place subgrade. However, comparison of these results with bar-graphs 4 and 5 showing the effects of compaction without ponding indicates that ponding did not increase the density materially. As mentioned in paragraph 13 these test sections were not saturated due to the nature of the soil, even though free water was maintained on the surface throughout the test. This reveals that it is not practicable to completely saturate the Eglin Field sands, and the partial degree of saturation obtained by sprinkling and ponding on the surface does not materially improve the results.

Conclusions of Preliminary Investigation

20. A study of the results presented in the preceding paragraphs indicates that the following conclusions may be made:

a. The 34,000-lb tractor and the 7,000-lb rubber-tired wheel load were unable to compact the sand subgrade, even at 32 coverages, sufficiently to meet the minimum requirements for VHB paving.

b. Ponding of the surface of the subgrade did not produce any increase in density over that obtained by compaction on natural or sprinkled subgrades.

A study of the above findings indicates that the methods employed to compact the test plot were not sufficient to bring its density up to the minimum requirements for VHB paving. The assumption that the bulk of the test plot represents the results of grading operations in cut seems to be borne out by preliminary density tests after grading operations in the new VHB runway areas, as very nearly the same densities were obtained there from grading operations alone. It is the opinion of this office that equipment considerably heavier than that normally used for grading operations at Eglin Field will be required on sands of this type in order to bring the densities at a 5-ft depth in the subgrade to the required 95 per cent of modified AASHO maximum density. The more elaborate investigation at Auxiliary Field No. 2 gives some indication of the equipment weights required.

PART III: INVESTIGATION AT AUXILIARY FIELD NO. 2

21. Upon receipt of the directive mentioned in paragraph 2, a reconnaissance of the entire Eglin Field area was made to select a suitable site for this investigation. The results of the preliminary investigation indicated that a large quantity of water would be needed to perform the tests proposed for saturated areas. Lack of sufficient surplus water at the main airfield precluded the possibility of performing the tests adjacent to the preliminary investigation site. Auxiliary Field No. 2, located on Florida State Road No. 285 some 12 miles northeast of the main airfield, was selected, as it was not being used at the time, and a 75,000-gal water tank was available together with the electric pumps necessary to keep it filled. Selection of Auxiliary Field No. 2 for this phase of the sand compaction investigation provided a tie-in with the previously-mentioned traffic tests performed at that field.

Layout

22. The layout of the test sections for the investigations performed at Auxiliary Field No. 2 is shown in figure 5. The five sections are described below:

- a. Section 1 consisted of a ponded and a dry or natural-moisture unit compacted with RD-8 tractor. Photograph 2 shows layout for this test section.
- b. Section 2 consisted of a ponded, a sprinkled, and a natural-moisture unit compacted with 15,000-lb wheel load Tournapull. Photograph 4 illustrates the layout of Section 2 which is also typical of layouts of Sections 3, 4 and 5.
- c. Section 3 consisted of a ponded, a sprinkled, and a natural-moisture unit compacted with 60,000-lb wheel load

Tournapull; a combination of 60,000-lb wheel load and loaded tractor was used in this section after completing the tests with the 60,000-lb wheel load equipment.

d. Section 4 consisted of a ponded, a sprinkled, and a natural-moisture unit compacted with RD-8 tractor loaded to approximately twice its original weight.

e. Section 5 consisted of a ponded, a sprinkled, and a natural-moisture unit compacted with 35,000-lb wheel load.

23. Each of the ponded and sprinkled units was 100 ft long with a 25-ft transition zone between the two. The natural-moisture units were 50 ft long. All sections except Section 5 were 30 ft wide. Section 5 had to be placed between Sections 3 and 4, and was only 25 ft wide. Photographs 2-10 are pertinent views of this investigation.

Compaction Equipment

24. An RD-8 tractor (photograph 3) similar to the one used in the preliminary investigation was secured for the compaction of Section 1. An 8-cu-yd Tournapull similar to the one used in the preliminary investigation was secured for compaction in Section 2. This was loaded with scrap iron (photograph 5) until its gross weight amounted to 60,000 lb or approximately 15,000 lb on each wheel. A large model scraper Tournapull was secured from the Ohio River Division for compaction of Section 3. This Tournapull was loaded with scrap iron and sand until the desired load of 35,000 or 60,000 lb was obtained on all 4 wheels (photograph 6); its 30- by 40-in. tires were inflated to 45-psi pressure. The 8-cu-yd Tournapull had two 16- by 21-in. tires on the rear axle which were inflated to 45-psi pressure and used two 21- by 24-in. tires on the front axle which were inflated to 38-lb pressure. Due to the worn

condition of the front tires, it was not deemed feasible to increase the air pressure in them to 45 psi. The RD-8 tractor used in Section 1 was loaded by constructing two compartments, one on either side, and filling these with steel shot until the gross weight was 80,000 lb for compaction of Section 4 (photographs 6 and 9).

Construction of Test Section

25. The area selected for these sand compaction tests was adjacent to an 8-in. water main which connected directly to the 75,000-gal water tank. A 6-in. water line was connected to the 8-in. main and carried to the sumps which are shown in the layout sketch, figure 5. The first four sections were graded, using the RD-8 tractor, the 8-cu-yd Tournapull, and a tractor-drawn patrol. Photograph 7 shows Section 3 after grading. In the dry or natural-moisture units and the sprinkled units, the top material was removed to a depth of about 12 in. In the ponded units, the top 18 to 24 in. of material was removed. Section 5 was graded with the same tractor and Tournapull at the conclusion of tests on Sections 1 to 4, inclusive. Experience in the preliminary investigation indicated the necessity of a reinforced turnaround for use at the ends of the rubber-tired wheel load sections. A supply of Irving Grid landing mat was used for these turnarounds (see photograph 8). During operation of the test it was found that the turnaround reinforcement was not necessary for the heavy Tournapull (60,000-lb wheel load and 35,000-lb wheel load). The sumps, mentioned above, were built with batter boards and the bottom was lined with rock to prevent erosion. After completing tests on Section 1, the water line was extended across Section 1 to the sump for Section 2.

Similarly, it was extended to the sump on Section 3. A view of water discharging into the sump for Section 2 is shown in photograph 4.

Field Sampling and Testing

Test pits

26. The field data secured in the Auxiliary Field No. 2 phase of the investigation were obtained from 33 test pits excavated at various stages of the test for the purpose of taking samples and making density and moisture determinations at 1-ft intervals down to a 6-ft depth. Towards the end of the study, a few of the pits were excavated to a depth of 10 ft. Records were kept on the amounts of water used in the ponded and sprinkled units. Location of all test pits is indicated on figure 5.

Method of determining per cent compaction

27. The laboratory tests on the density samples showed a considerable variation in the values of maximum density obtained by the modified AASHO compaction test. As in the preliminary investigation, a relationship between the per cent passing the No. 200 sieve and the maximum density was established. The resulting straight line gives a density about 1-1/2 lb per cu ft less than the similar line established for the material at the main Eglin Field for a comparable percentage of fines. The line used for computing all the per cent compaction data in the Auxiliary Field No. 2 investigation is shown in the right hand chart on figure 3. A sieve analysis was run on each density sample taken in order to make these computations. Figure 6 shows the results of sieve analysis tests on 220 samples. The uniformity of the material is denoted by the narrow range in the maximum variation of these tests. In comparison with figure 2

the sands at Auxiliary Field No. 2 have about 3 per cent more fines on the average than those at the main Eglin Field and exhibit a slightly wider variation in the material finer than the No. 60 sieve.

Application of Water

28. The ponded units of the test sections were filled with water to a depth of 3 or 4 in. just before tracking was begun. In Section 1 the ponded area took approximately 44,000 gal of water before and during the test and it has been computed that approximately 0.93 gal per sq yd per min infiltrated into the sand subgrade beneath this area during that time. The ponded unit of Section 2 took 62,400 gal of water during the first 12 coverages, and the next day an additional 29,000 gal of water was used to complete 25 coverages. Thirty thousand (30,000) gal of water was applied before and during the first 4 coverages of the 60,000-lb wheel load in Section 3 (see photograph 10); operations that day were stopped by a heavy downpour which lasted over an hour. The next day 15,000 gal of water was used, and the total coverages equalled 12 when operations ceased. The following day approximately 10,000 gal of water was used and the total coverages reached 23. On the next day about 16,000 gal of water was applied and the last 2 coverages completed making a total of 25.

29. To expedite the test a ditch was cut between Sections 3 and 4 (see photograph 6), thus keeping both sections flooding during the tests on the latter section. It was necessary to use more than 125,000 gal of water during the test of Section 4 to keep the ponded area at desired water level. Section 5 ponded area was also flooded from the sump in

Section 3.

30. The water wagon used in the sprinkled sections held 900 gal. It was run over the sprinkled area just ahead of the particular tracking equipment being used and applied approximately 0.5 gal per sq yd (see photographs 4 and 6). During 6 coverages of the 15,000-lb wheel load, a total of 4 gal per sq yd was applied to the entire sprinkled area in approximately 2 hr. Approximately this rate of application of water was used in all sprinkled test items.

Results of Auxiliary Field Tests

31. The moisture-density data given in detail in table 3 have been analyzed and plotted in bar-graph form on figure 7. These bar-graphs are set up in the same manner as those in figure 4 for the preliminary investigation to facilitate comparison with the minimum requirements and with each other.

32. Prior to grading in the test area, the average per cent density varied from about 90 per cent at the top of the ground to 86 per cent which seemed to be more or less constant from 2 to 6 ft below the ground as shown on table 3 and bar-graph 2 of figure 7. Comparison with figure 4 indicates that the main airfield subgrade has densities 4 to 6 per cent higher expressed in terms of per cent compaction than the sand at Auxiliary Field No. 2. The grading operations increased the degree of compaction from 3 to 7 per cent as indicated by comparing bar-graphs 2 and 3, figure 7, and as shown in table 3. These increased densities, however, do not come up as high as those in the preliminary investigation at the main field. This could be due to the fact that the test section

grading operations at Auxiliary Field No. 2 were not as extensive as the grading operations at the site of the preliminary investigations.

Section 1

33. The compaction of Section 1 with 12 coverages of the tractor on the natural-moisture subgrade showed only an increase in per cent compaction of 2-1/2 for the top 2 ft and none below that depth when compared to that resulting from grading operations alone as may be seen by comparing bar-graphs 3 and 7 of figure 7. No increase in density resulted from an additional six coverages. The effect of ponding the surface of the test units did not produce any increase in density over the natural water content units and apparently resulted in a definite decrease in density with an increase in coverages from 6 to 18 as shown by bar-graphs 4, 5 and 6 and a comparison of these with 7 and 8.

Section 2

34. Compaction of Section 2 with 25 coverages of the 15,000-lb wheel load on the natural, sprinkled and ponded subgrades resulted in some increase in density in the top 3 ft over grading operations (see bar-graphs 3, 12, 13 and 14 and table 3). This method of compaction showed a slight improvement when compared with results from compaction with the 34,000-lb RD-8 tractor, as shown by bar-graphs 4-8 inclusive. Again no improvement in compaction was noted in the sprinkled or ponded units over that obtained in the natural subgrade units.

Section 3

35. This section, which was compacted by 25 coverages of the

60,000-lb wheel load, showed a marked increase in density all the way down to the 6-ft depth, with the top 3 ft being over 100 per cent of maximum as is shown by bar-graphs 19, 20 and 21 and table 3. Again no beneficial result could be seen from the use of water as an aid to compaction. Table 3 and bar-graphs 22 and 23, figure 7, show that the use of both the loaded tractor and the 60,000-lb wheel load Tournapull caused some increase in the densities of Section 3. These densities are somewhat higher for the combined tracking units than those for either of the tracking units alone. It should be remembered that this section had the 60,000-lb wheel load tracking prior to using both units.

Section 4

36. Compaction in Section 4 by 12 coverages of a tractor loaded to 80,000 lb caused an appreciable increase in per cent compaction, but the values obtained were not as high as those under the 60,000-lb wheel load (see bar-graphs 9, 10, 11, 19, 20 and 21). No increase in compaction could be noted from the use of water in this section.

Section 5

37. The test pits in Section 5, except those placed before grading, were excavated to a 10-ft depth. The values shown in table 3 and the bar-graphs of figure 7 indicate that compaction by the 35,000-lb wheel load resulted in densities in the upper 6 ft that were slightly greater than those obtained by the loaded tractor in Section 4, and somewhat less than those obtained with the 60,000-lb wheel load in Section 3. With one exception, the densities were above 90 per cent down to the 10-ft depth. The 35,000-lb wheel load increased the density some 3 to 9 per cent in

the top 5 ft as shown by bar-graphs 16, 17 and 18. The comparison below this depth is unsatisfactory as the one pit excavated to a 10-ft depth in this area prior to compaction encountered a lean sand clay in the bottom 3 ft. Densities in the sprinkled and ponded units showed no appreciable increase over the natural subgrade unit.

Effect of ponding

38. The amount of water required to flood the ponded areas after start of tracking was markedly less than that originally thought to be required. The reason for this became apparent when all the water infiltrated into the subgrade in the first ponded area. The surface of the area had a thin film of silt which had been brought into suspension from the churning action of the treads or wheels of the tracking equipment. This same phenomenon occurred in all sections. During periods when no tracking was in progress, it was observed that the water infiltrated into the subgrade sand at a much slower rate than during periods of tracking. This indicated that the action of the tracking tended to keep the surface of the subgrade at least partially free of the film of silt. An effort was made in the vicinity of Test Pit No. 23 in the ponded unit of Section 3 to determine the water content beneath the subgrade surface just after the free water had disappeared from it. The results showed from 6 to 8 per cent water down to 4-ft depth, which were approximately the same as found when Test Pit No. 23 was dug several days after completion of the test in that section. These values bear out the findings made in the preliminary investigation that complete saturation was far from being obtained during the tests on the ponded units.

PART IV: CONCLUSIONS

39. The following conclusions directly applicable to the Eglin Field sand were derived from the results of this investigation:

- a. The compaction of the Eglin Field sand subgrade material to the minimum requirements for VHB paving requires the use of heavier equipment than ordinarily employed at Eglin Field in grading operations. Little if any increased compaction resulted from use of equipment of the same type and weight as used to grade the site.

- b. The study indicates that wheel loads of 35,000 lb will satisfy the minimum density requirements for VHB paving at Eglin Field, and that a tractor loaded to 80,000 lb very nearly satisfies the requirements.

- c. When 6 coverages of the compacting equipment do not obtain the desired degree of compaction, heavier equipment rather than more coverages is required. Very little, if any, improvement was noted when coverages in excess of 6 were used, but increased weight of compacting equipment showed considerable improvement.

- d. The Eglin Field sand subgrade did not compact more readily when water was used, either by sprinkling or ponding; therefore the use of water as an aid to compaction is not justified. Since the free-draining soil conditions at the site of these tests did not permit a very high degree of saturation at any appreciable depth below the ground surface, the results did not indicate whether or not any benefit would result from complete or nearly complete saturation down to appreciable depths in the sand.

- e. The results show that there is some difference in the two sands represented by the subgrade at Eglin Field and the subgrade at Auxiliary Field No. 2. Consequently, it is probable that lighter loads than those indicated in the Auxiliary Field No. 2 investigation may satisfy the VHB requirements at the main field.

40. In addition to the specific conclusions stated above, it is believed that the statements listed below are applicable, in general, to poorly compacted clean sand subgrades:

- a. Appreciable compaction can be obtained to depths up to 5 ft with wheel loads of 35,000 lb or higher.

b. Weight of compaction equipment is more important in increasing density than additional passes beyond a reasonable minimum.

TABLES

Table 1

Preliminary Investigation

DENSITY, WATER CONTENT AND PER CENT COMPACTION BEFORE AND AFTER TRACKING

			After Compaction (Dry)			After Compaction (Wet)			After Grading Prior to Compaction			
Compaction Equipment	Number of Coverages	Depth in Ft	Water Content %	Dry Density Lb/Cu Ft	% Compaction	Water Content %	Dry Density Lb/Cu Ft	% Compaction	Depth in Ft	Water Content %	Dry Density Lb/Cu Ft	% Compaction
34,000-lb RD-8 Tractor	6	0-1	3.1	105.6	100	4.3	107.8	101	0-1	3.4	105.1	98
		1-2	3.2	107.6	101	3.8	110.1	101	1-2	3.5	108.0	102
		2-3	3.1	101.4	97	3.5	102.4	96	2-3	4.0	102.3	97
		3-4	3.4	98.9	94	3.9	99.8	95	3-4	4.7	100.2	95
		4-5	4.0	98.4	93	4.4	99.0	93	4-5	4.4	97.9	92
		5-6	4.4	97.5	93	4.4	100.4	94	5-6	3.8	97.9	92
	32	0-1	2.8	107.4	101	7.2	109.6	101				
		1-2	3.4	107.6	102	5.0	106.6	101				
		2-3	3.4	101.6	97	4.4	102.4	97				
		3-4	4.1	98.6	93	4.5	98.4	94				
		4-5	4.6	98.0	92	4.8	98.2	92				
		5-6	4.7	98.2	92	5.0	97.0	91				
7,000-lb Wheel load (8-cu-yd Tournapull)	6	0-1	5.3	103.5	96	3.9	106.8	99				
		1-2	3.4	107.2	101	3.2	109.0	102				
		2-3	3.2	100.3	95	3.2	103.8	98				
		3-4	2.8	99.5	95	3.5	99.4	95				
		4-5	3.4	99.1	93	3.8	98.2	94				
		5-6	3.7	100.5	94	4.4	98.7	92				
	32	0-1	3.4	108.4	99	5.0	108.0	103				
		1-2	4.3	109.3	101	3.7	109.8	103				
		2-3	5.0	100.6	94	3.6	101.6	97				
		3-4	4.4	96.6	92	4.0	98.4	94				
		4-5	4.6	96.8	93	4.1	97.6	92				
		5-6	4.7	96.8	92	5.1	98.8	93				

Note: Values tabulated are average of from 2 to 4 test pits.

Table 2

Preliminary Investigation

DENSITY, WATER CONTENT AND PER CENT COMPACTION OF SPECIAL SATURATED TEST AREA BEFORE AND AFTER COMPACTION WITH 34,000-LB RD-8 TRACTOR

Before Compaction				After Compaction			
Depth Ft	Water Content %	Dry Density Lb/CuFt	% Compaction	Depth Ft	Water Content %	Dry Density Lb/CuFt	% Compaction
Before Soaking				5-Min Soaking Prior to 6 Coverages*			
0-1	4.4	107.2	97	0-1	5.4	111.7	101
1-2	4.6	105.0	96	1-2	4.8	106.9	98
2-3	5.0	99.9	93	2-3	4.6	101.9	95
3-4	5.0	97.3	91	3-4	5.1	98.9	92
4-5	3.8	97.0	91	4-5	5.3	98.2	93
5-6	3.3	97.1	91	5-6	6.0	98.0	93
After 3-Hr Soaking, 0 Coverages				5-Min Soaking Prior to 20 Coverages*			
0-1	4.2	105.6	97	0-1	5.8	109.6	100
1-2	3.8	101.2	94	1-2	4.8	107.9	100
2-3	4.0	98.6	91	2-3	4.4	102.3	96
3-4	3.7	97.8	92	3-4	5.0	98.2	93
4-5	3.4	96.8	91	4-5	4.7	97.8	92
5-6	3.7	97.1	91	5-6	4.4	97.3	88
				60-Min Soaking Prior to 6 Coverages*			
				0-1	5.6	112.1	104
				1-2	5.1	107.2	99
				2-3	4.7	101.9	92
				3-4	5.0	98.2	92
				4-5	5.0	97.5	90
				5-6	5.4	96.3	90

Note: Values tabulated are from individual test pits.

* Soaking of all test areas continued during tractor coverages.

Table 3

Investigation at Auxiliary Field No. 2

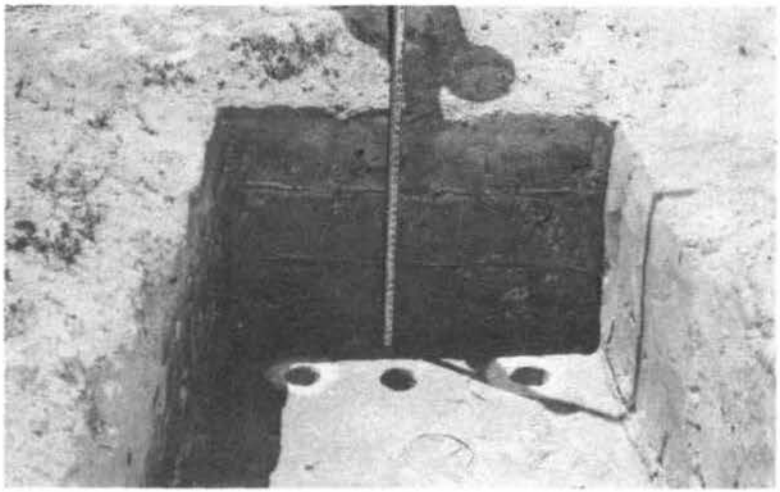
DENSITY, WATER CONTENT AND PER CENT COMPACTION BEFORE AND AFTER TRACKING

				Natural-Water Area			Partially-Soaked Area			Soaked Area			
Section	Number of Cov-erages	Tracking Speed Mi/Hr	Depth in Ft	Water Content %	Dry Density Lb/CuFt	% Compac-tion	Water Content %	Dry Density Lb/CuFt	% Compac-tion	Water Content %	Dry Density Lb/CuFt	% Compac-tion	Remarks
Density &	0		0-1				3.5	108.8	99	3.5	105.5	96	Average of
water con-			1-2				3.9	105.3	95	4.0	104.0	94	3 test pits
tent of			2-3				4.2	101.6	93	4.3	99.8	92	
test area			3-4				4.5	98.5	90	4.2	96.5	90	
after			4-5				4.1	97.5	91	4.0	96.0	90	
grading			5-6				4.0	97.7	92	3.9	95.9	90	
prior to			6-7							5.5	98.9	94	
compaction			7-8							9.0	103.6	93*	*Different
			8-9							7.6	103.0	93*	material
			9-10							7.6	103.4	93*	containing more fines passing No. 200 sieve
1 - 34,000-	6	1.1	0-1							6.0	109.5	101	
lb RD-8			1-2							5.6	105.0	97	Individual
Tractor			2-3							5.8	99.2	92	test pits
			3-4							5.1	96.7	92	
			4-5							4.5	96.4	92	
			5-6							4.7	95.4	90	
1 - 34,000-	12	1.1	0-1	4.1	107.4	99				8.4	107.3	98	Individual
lb RD-8			1-2	4.0	104.6	97				6.3	104.6	95	test pits
Tractor			2-3	4.2	101.2	93				6.2	101.4	93	
			3-4	4.3	95.5	88				5.5	95.9	90	
			4-5	3.8	98.1	91				5.4	95.5	91	
			5-6	4.0	94.1	89				5.0	95.6	91	
1 - 34,000-	18	*	0-1	3.3	106.7	98				7.2	105.0	95	*First 12
lb RD-8			1-2	3.9	103.2	94				5.4	104.9	94	coverages
Tractor			2-3	4.0	99.0	90				5.8	100.9	93	at 1.1 mi/
			3-4	4.2	95.9	88				5.3	96.6	91	hr; last 6
			4-5	3.7	95.3	90				5.0	95.3	89	coverages
			5-6	3.6	93.5	88				5.4	94.7	90	at 3.6 mi/ hr Individual test pits
2 - 15,000-	25	1.5	0-1	3.0	113.8	103	5.2	107.8	97	5.7	110.7	98	
lb Wheel			1-2	3.8	108.6	98	4.5	108.9	98	4.9	108.9	102	Individual
load			2-3	4.3	103.8	94	4.8	102.5	93	4.7	102.8	95	test pits
			3-4	4.2	97.8	90	5.1	96.2	87	3.9	95.2	89	
			4-5	3.6	97.5	88	4.7	95.1	88	3.8	96.9	88	
			5-6	3.7	95.4	92	4.5	94.4	89	4.2	97.2	92	
3 - 60,000-	25	1.5	0-1	4.1	112.5	102	5.8	117.5	106	6.8	109.7	101	Individual
lb Wheel			1-2	3.9	113.0	101	5.0	115.2	104	6.3	115.1	104	test pits
load			2-3	4.1	108.5	102	5.3	113.0	103	6.0	113.3	102	
			3-4	4.6	106.0	97	5.1	107.0	98	4.7	104.2	97	
			4-5	4.1	102.8	96	4.8	103.2	96	4.4	99.7	94	
			5-6	3.6	102.8	96	4.3	100.7	94	4.3	100.6	94	
3 - 60,000-	12	1.5	0-1	7.7	115.4	105				9.6	114.4	104	Additional
lb Wheel			1-2	6.8	116.5	106				6.1	115.9	106	tracking
load + RD-8			2-3	5.7	111.1	102				5.2	114.0	104	
Tractor			3-4	5.7	106.5	98				4.4	107.7	100	Individual
loaded to			4-5	5.8	100.2	94				7.2	102.3	96	test pits
80,000 lb gross weight			5-6	5.3	97.7	93				6.4	100.1	95	
4 - RD-8	12	1.5	0-1	6.2	111.4	102	5.1	112.1	102	6.2	107.8	99	Individual
Tractor			1-2	4.8	111.3	102	5.4	109.2	101	4.8	112.0	102	test pits
loaded to			2-3	5.4	105.8	97	5.7	104.8	97	4.6	108.9	100	
80,000 lb			3-4	5.4	101.8	95	5.6	100.9	94	3.9	103.4	96	
gross weight			4-5	4.5	98.1	92	5.3	98.6	94	3.7	100.9	96	
			5-6	3.9	98.4	93	5.6	99.0	94	3.9	98.3	94	
5 - 35,000-	6	2	0-1	9.0	112.7	104	5.9	111.5	103	4.4	110.4	101	Individual
lb Wheel			1-2	7.1	113.2	103	5.4	111.9	103	4.9	117.8	108	test pits
load			2-3	5.6	108.6	99	5.4	108.0	99	4.1	108.2	102	
			3-4	5.3	103.7	94	4.8	101.4	95	3.8	100.9	96	
			4-5	4.9	99.6	95	4.3	100.0	95	3.5	101.0	96	
			5-6	4.7	97.0	94	5.0	98.9	94	3.7	98.8	95	
			6-7	4.4	96.5	93	5.0	98.3	94	3.8	97.0	94	
			7-8	4.4	96.3	93	4.8	96.8	92	4.4	96.2	92	
			8-9	4.4	96.7	93	5.8	96.5	91	6.1	99.0	90	
			9-10	5.2	97.4	95	7.3	101.0	90	5.4	97.6	89	

PHOTOGRAPHS

Excavating hole for field density determination

Determining volume of density hole



Determining depths in test pit

Test pit several days after excavating

Photograph 1. Density determinations by sand displacement method in preliminary investigation

Photograph 2. Section 1 after tracking

Photograph 3. RD-8 tractor in ponded area of Section 1

6-in. pipe discharging into sump for ponded area

Conclusion of tracking with water still in ponded area

Sprinkling operation during tracking

Sprinkled and natural-water areas during tracking; latter area covered with mat

Photograph 4. Ponded, sprinkled and natural-water areas of Section 2

Photograph 5. Tournapull loaded to 15,000 lb per wheel entering ponded area of Section 2

Large Tournapull loaded to 60,000-lb wheel load

Tracking in Section 3

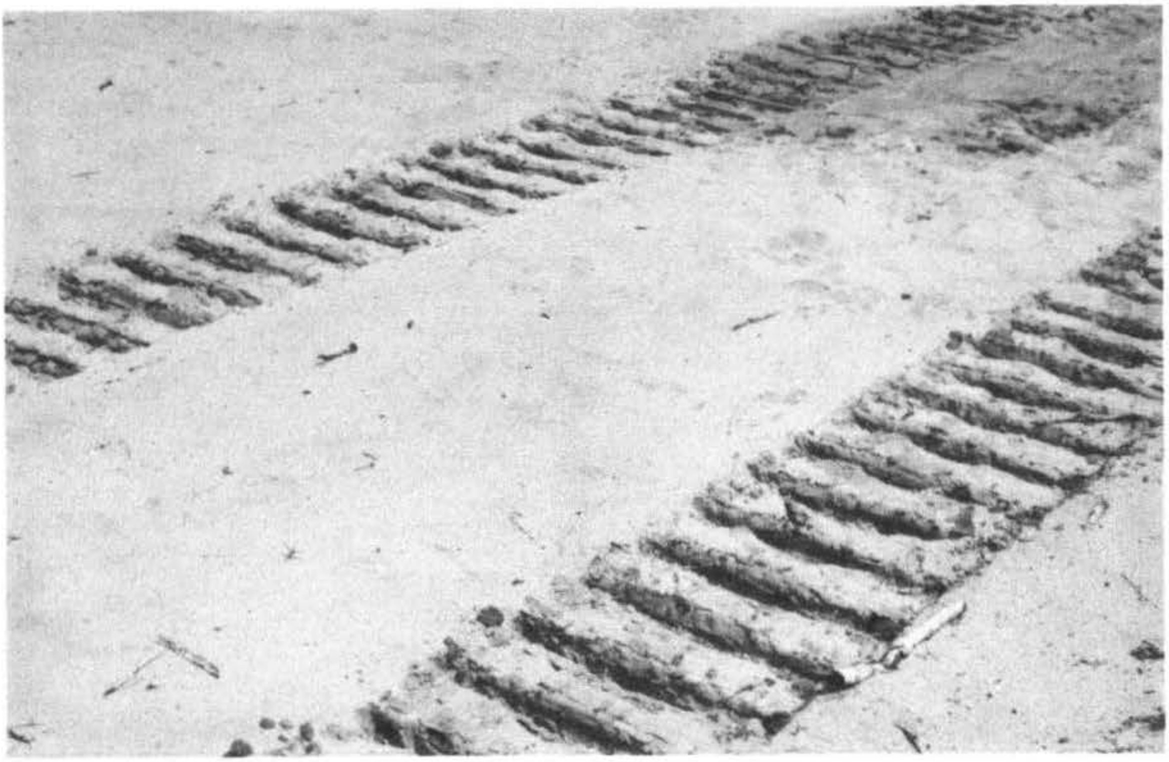
Loaded tractor & large Tournapull on Section 3
after tracking by Tournapull alone

Beginning tracking with 80,000-lb tractor, Section 4
Ditch between Sect.3 & 4 left, both ponded areas flooded

Photograph 6. Equipment and tracking on Sections 3 and 4

Photograph 7. Section 3 after grading

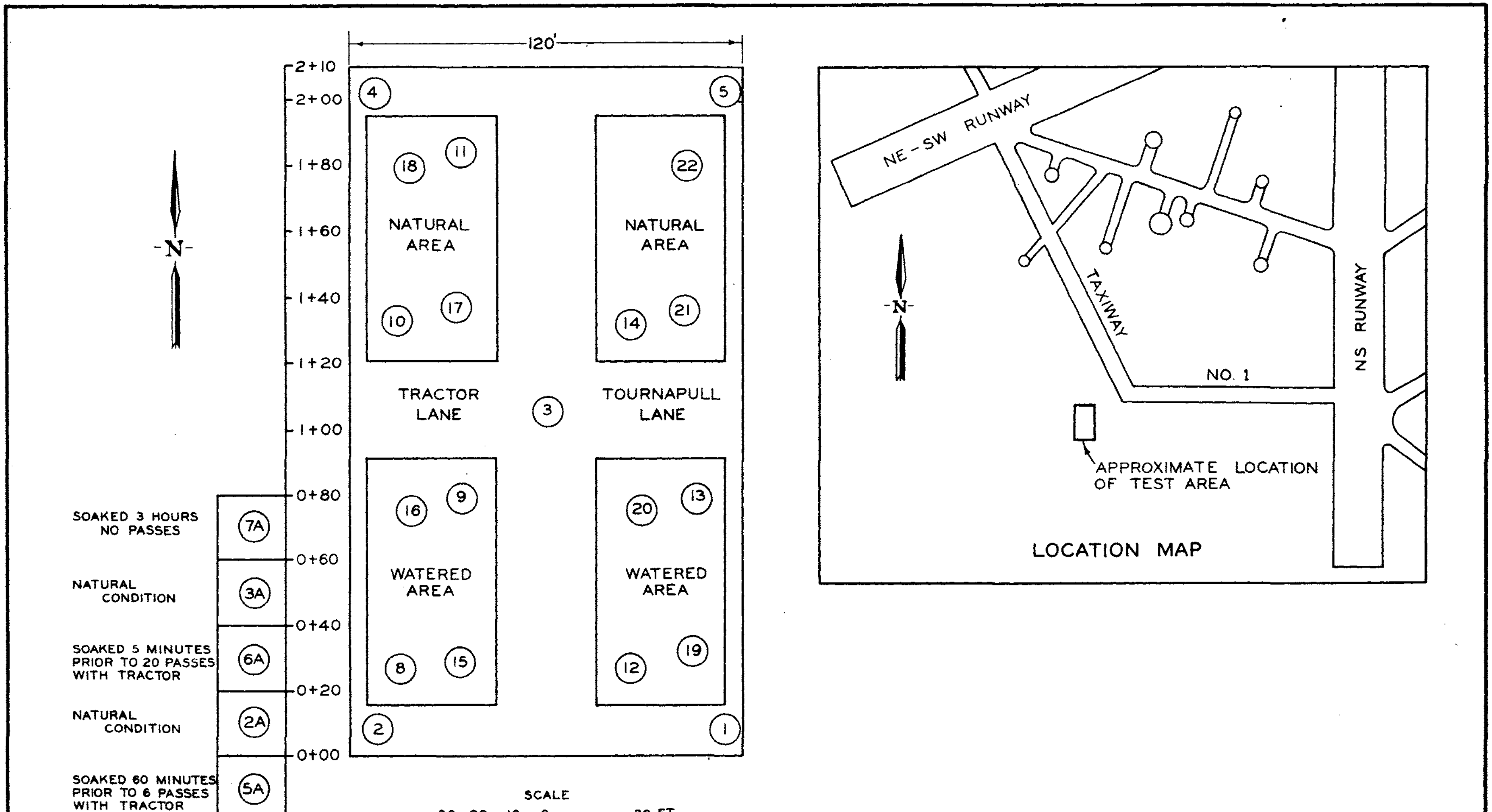
Photograph 8. Landing mat turnaround at south end of Section 2



Photograph 9. Tread marks of 80,000-lb tractor, Section 4

Photograph 10. Tire marks of 60,000-lb wheel load in sprinkled area of Section 3

FIGURES

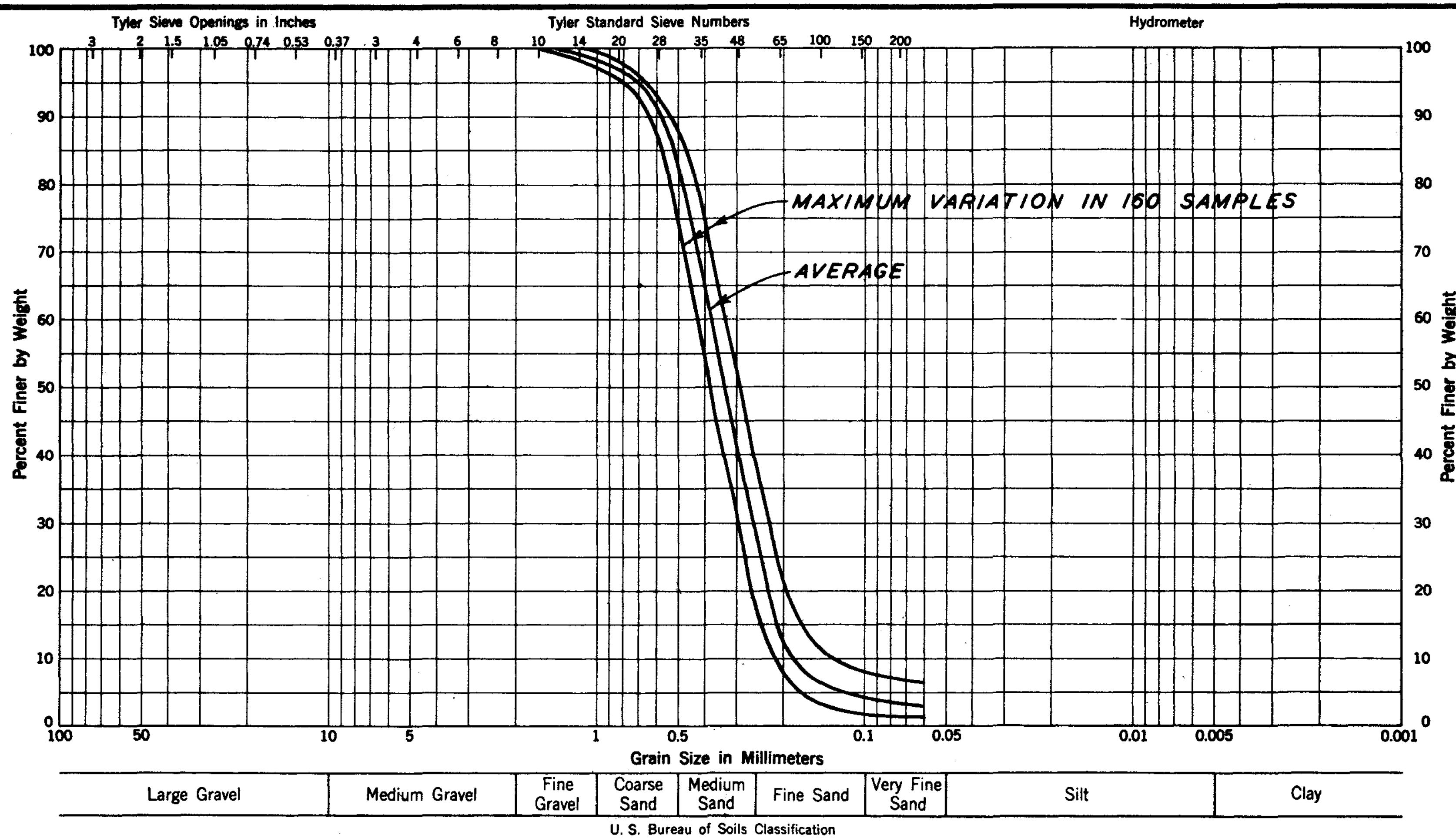


SOIL COMPACTION INVESTIGATION
SAND SUBGRADE COMPACTION TESTS
EGLIN FIELD, FLORIDA

LAYOUT OF TEST AREA FOR PRELIMINARY INVESTIGATION

FIGURE 1

FIGURE 2

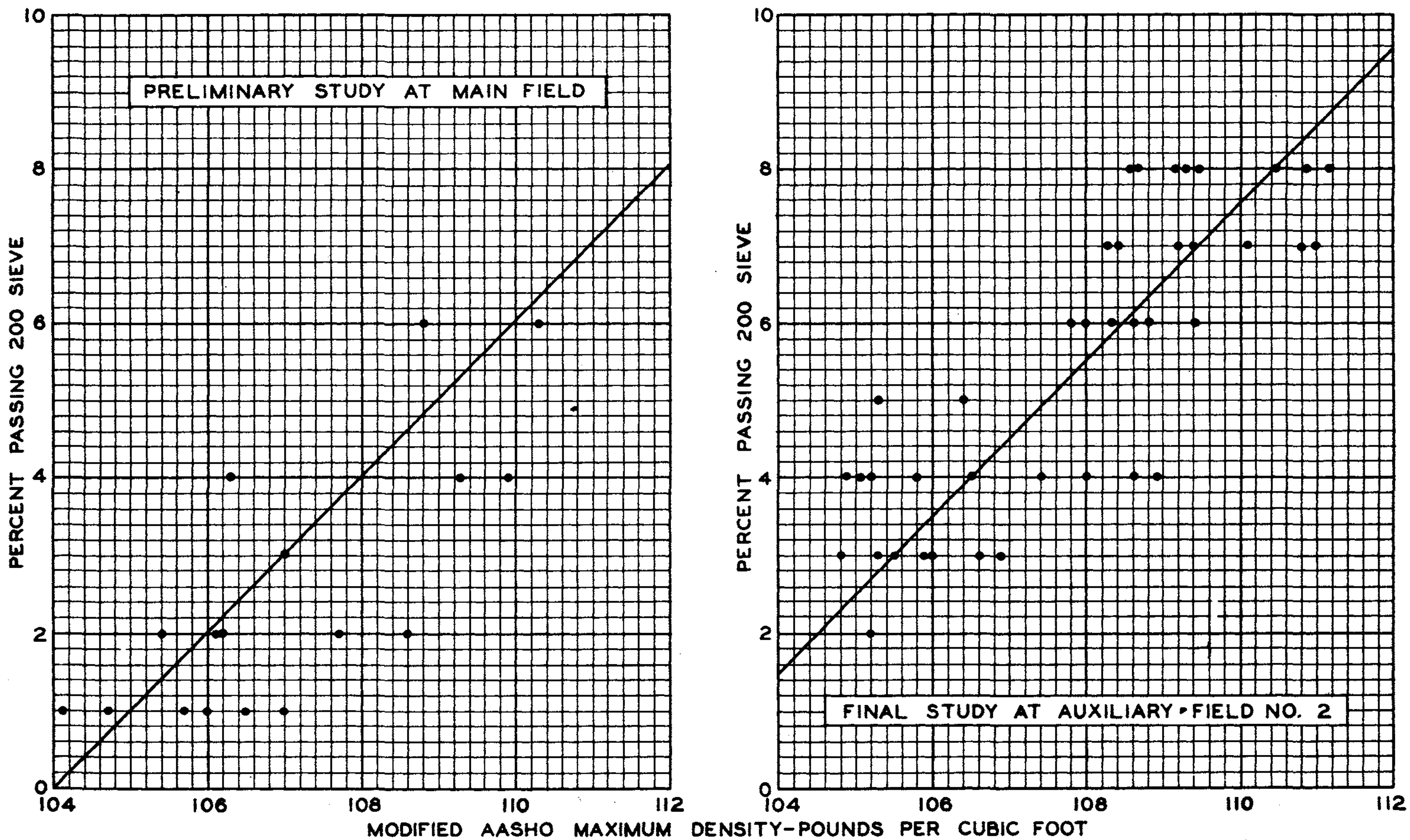


SOIL COMPACTION INVESTIGATION

SAND SUBGRADE COMPACTION TESTS

EGLIN FIELD, FLORIDA

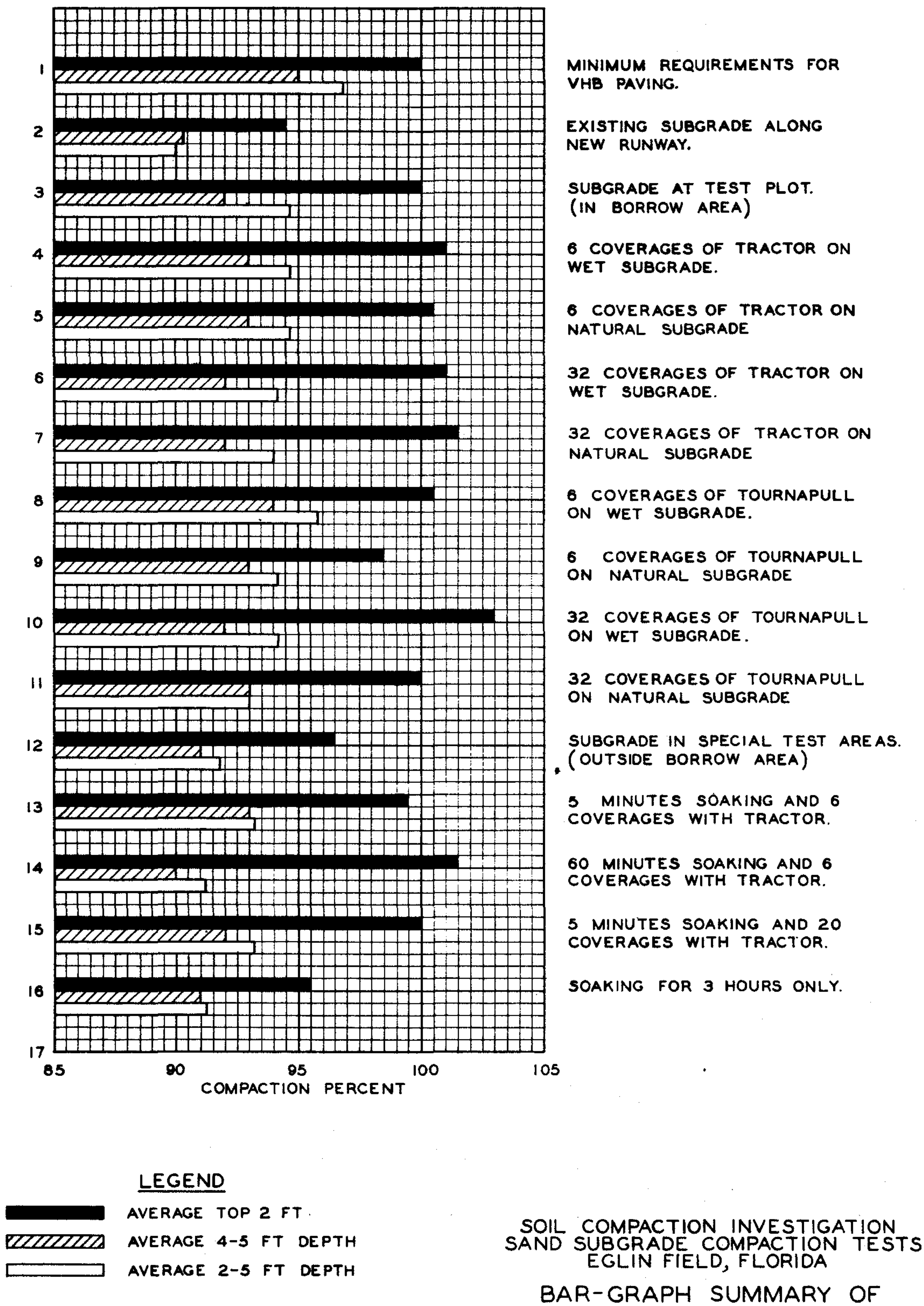
MECHANICAL ANALYSIS CURVES FROM PRELIMINARY INVESTIGATION



SOIL COMPACTION INVESTIGATION
SAND SUBGRADE COMPACTION TESTS
EGLIN FIELD, FLORIDA

MODIFIED AASHO DENSITY VERSUS
PERCENT PASSING 200 MESH SIEVE

FIGURE 3



SOIL COMPACTION INVESTIGATION
SAND SUBGRADE COMPACTION TESTS
EGLIN FIELD, FLORIDA

BAR-GRAPH SUMMARY OF RESULTS OF PRELIMINARY INVESTIGATION

FIGURE 4

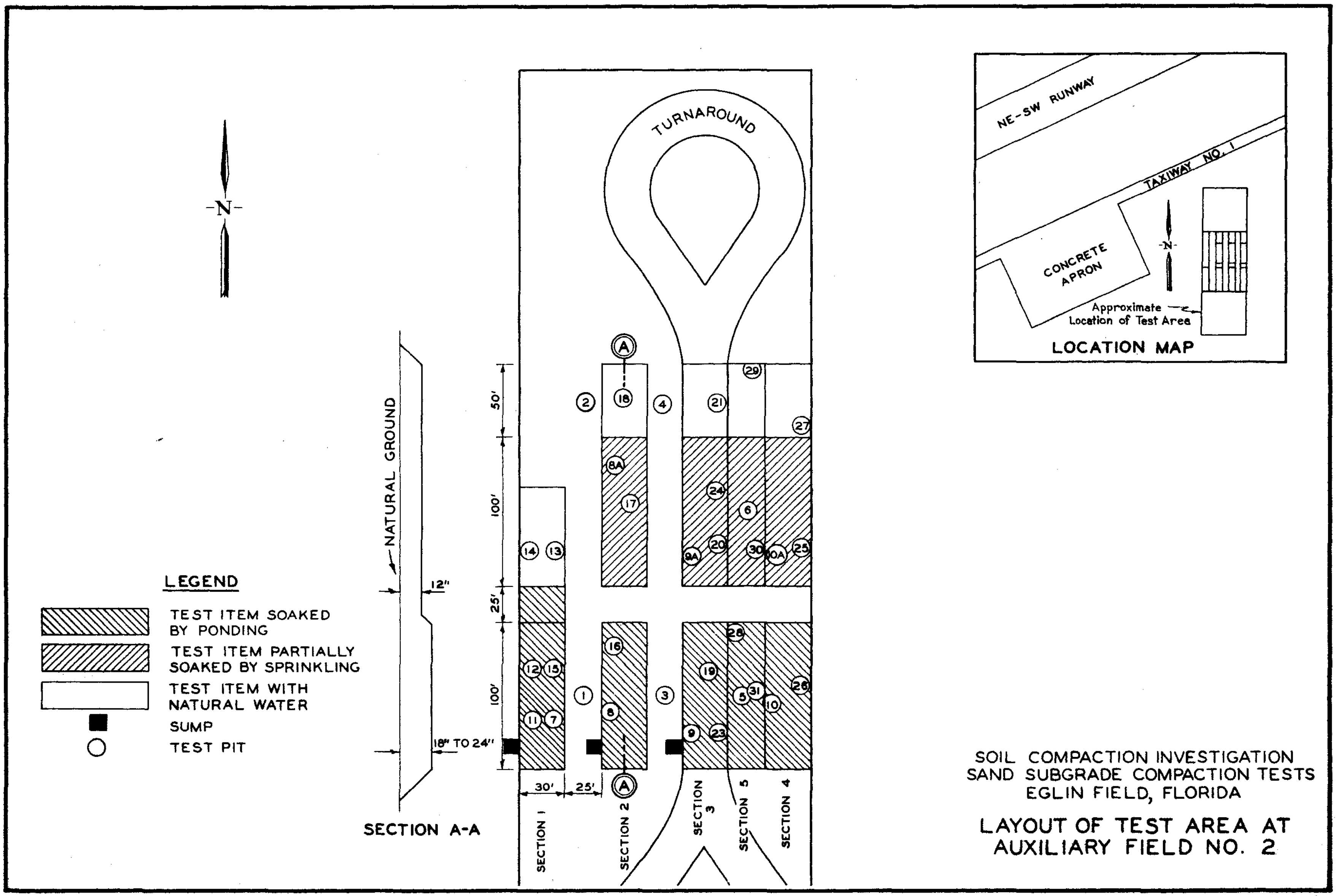
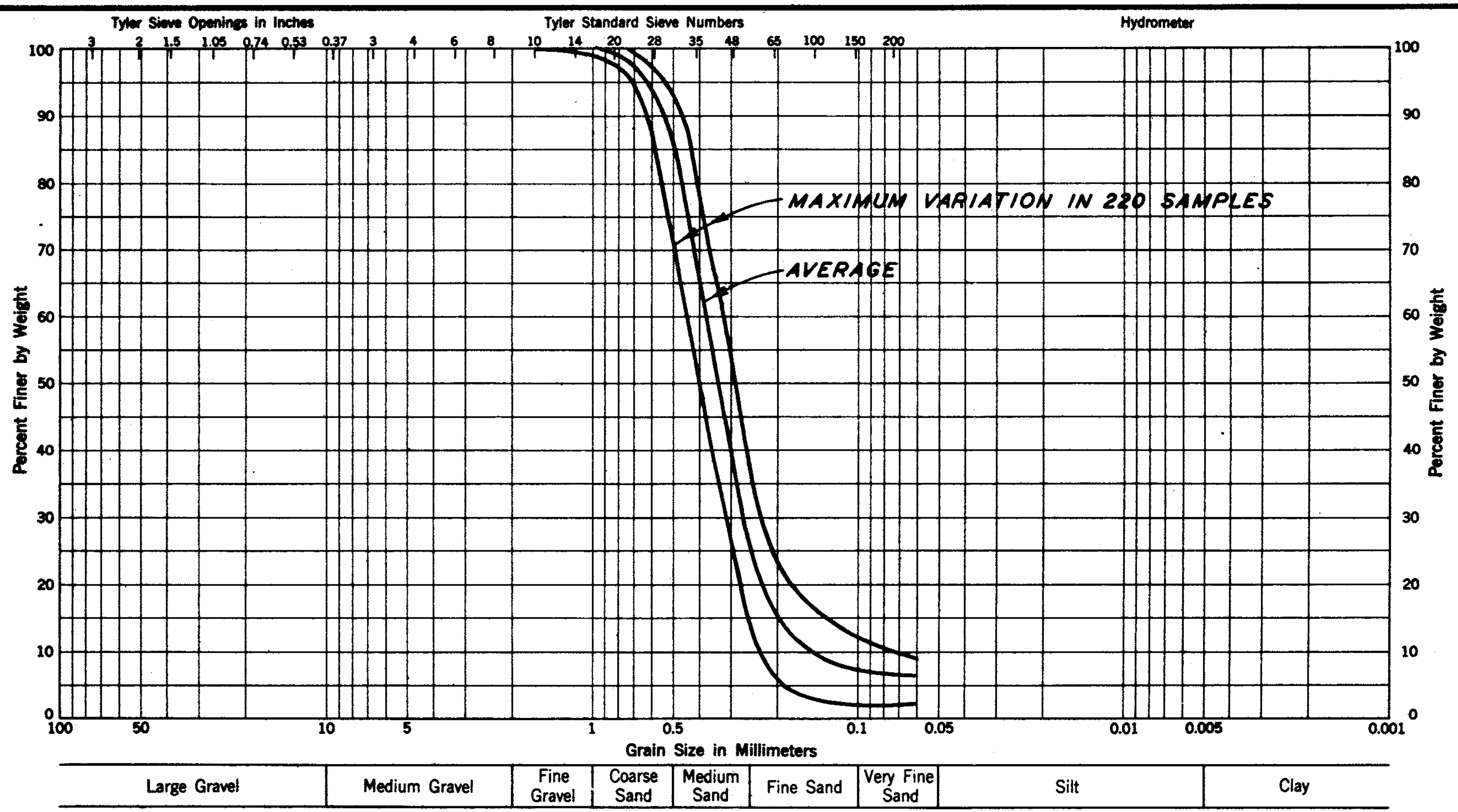

TURNAROUND
LOCATION MAP
NE-SW RUNWAY
TAXIWAY NO. 1
CONCRETE APRON
Approximate Location of Test Area
N
NATURAL GROUND
12"
18" TO 24"
SECTION A-A
LEGEND
TEST ITEM SOAKED BY PONDING
TEST ITEM PARTIALLY SOAKED BY SPRINKLING
TEST ITEM WITH NATURAL WATER
SUMP
TEST PIT
50'
100'
25'
100'
30'
25'
A
SECTION 1
SECTION 2
SECTION 3
SECTION 5
SECTION 4
SOIL COMPACTION INVESTIGATION
SAND SUBGRADE COMPACTION TESTS
EGLIN FIELD, FLORIDA
LAYOUT OF TEST AREA AT
AUXILIARY FIELD NO. 2

FIGURE 5

FIGURE 6



U. S. Bureau of Soils Classification

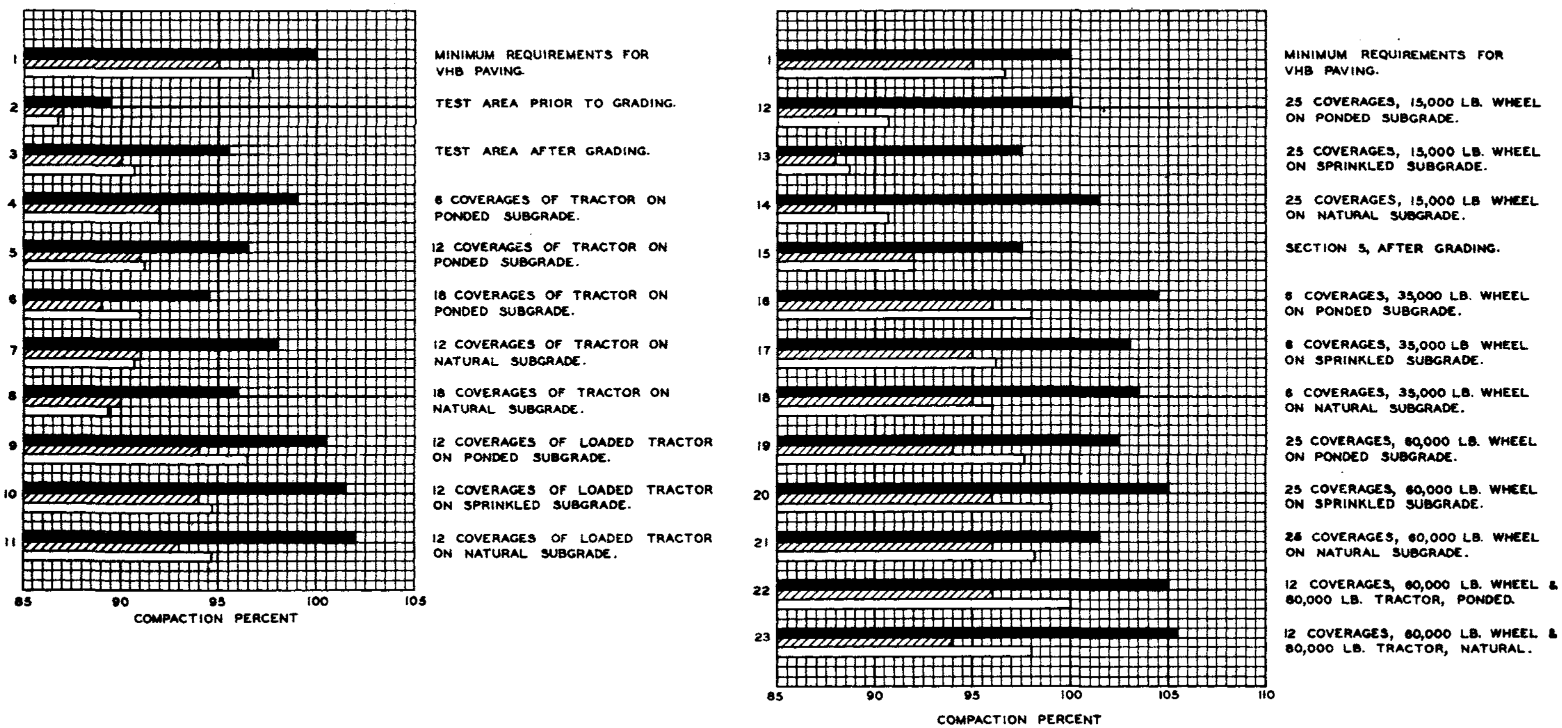
SOIL COMPACTION INVESTIGATION

SAND SUBGRADE COMPACTION TESTS

EGLIN FIELD, FLORIDA

MECHANICAL ANALYSIS CURVES

FROM AUXILIARY FIELD NO. 2



LEGEND

AVERAGE TOP 2 FT.
AVERAGE 4-5 FT. DEPTH
AVERAGE 2-5 FT. DEPTH

SOIL COMPACTION INVESTIGATION
SAND SUBGRADE COMPACTION TESTS
EGLIN FIELD, FLORIDA

BAR-GRAPH SUMMARY OF RESULTS
OF TEST AT AUXILIARY FIELD NO. 2

FIGURE 7